Agile Science Operations: A new approach for primitive bodies exploration

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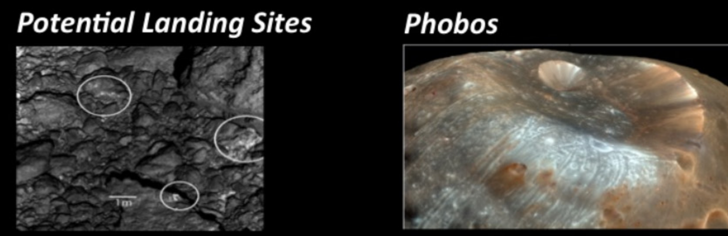
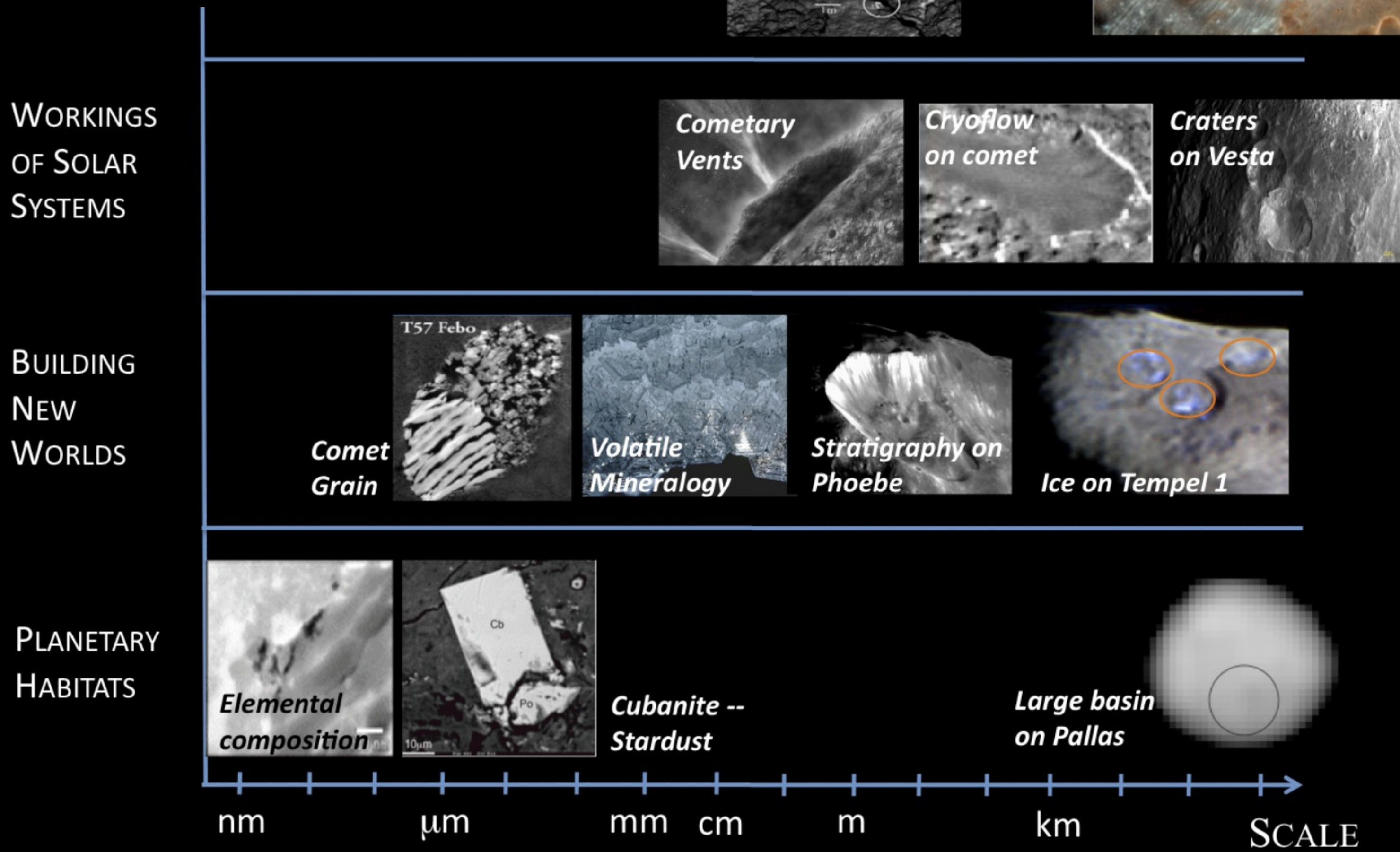
Primitive bodies: key measurements





Reproduced from Castillo-Rogez, Pavone, Nesnas, Hoffman, "Expected Science Return of Spatially-Extended In-Situ Exploration at Small Solar System Bodies," *IEEE Aerospace* 2012.

Collecting this data is hard!

Targets have diverse morphologies, compositions

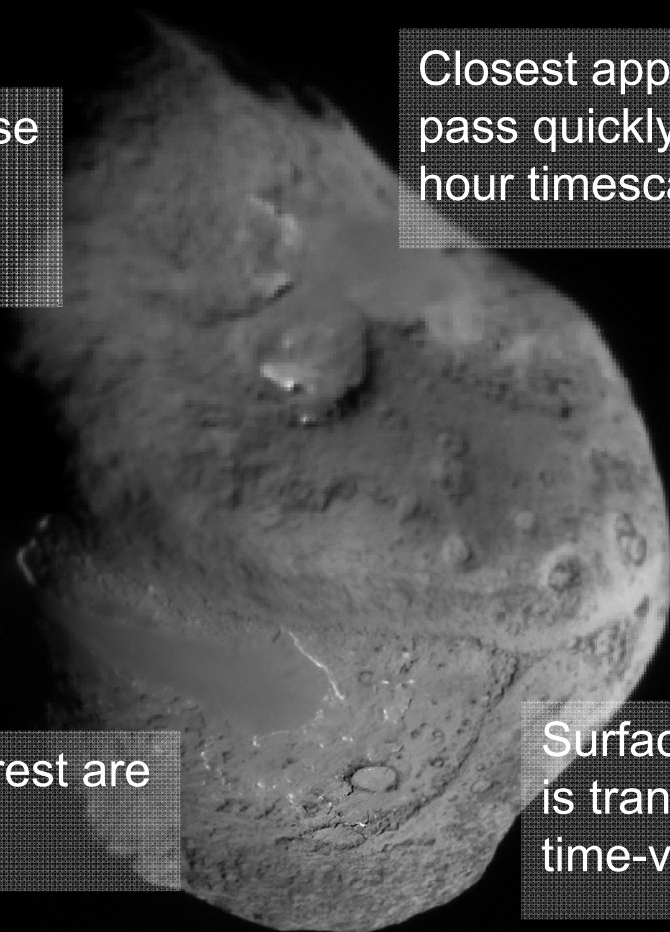
Closest approach may pass quickly (sub-hour timescales)

Target locations are not known in advance

Geometry and illumination constraints

Features of interest are highly localized

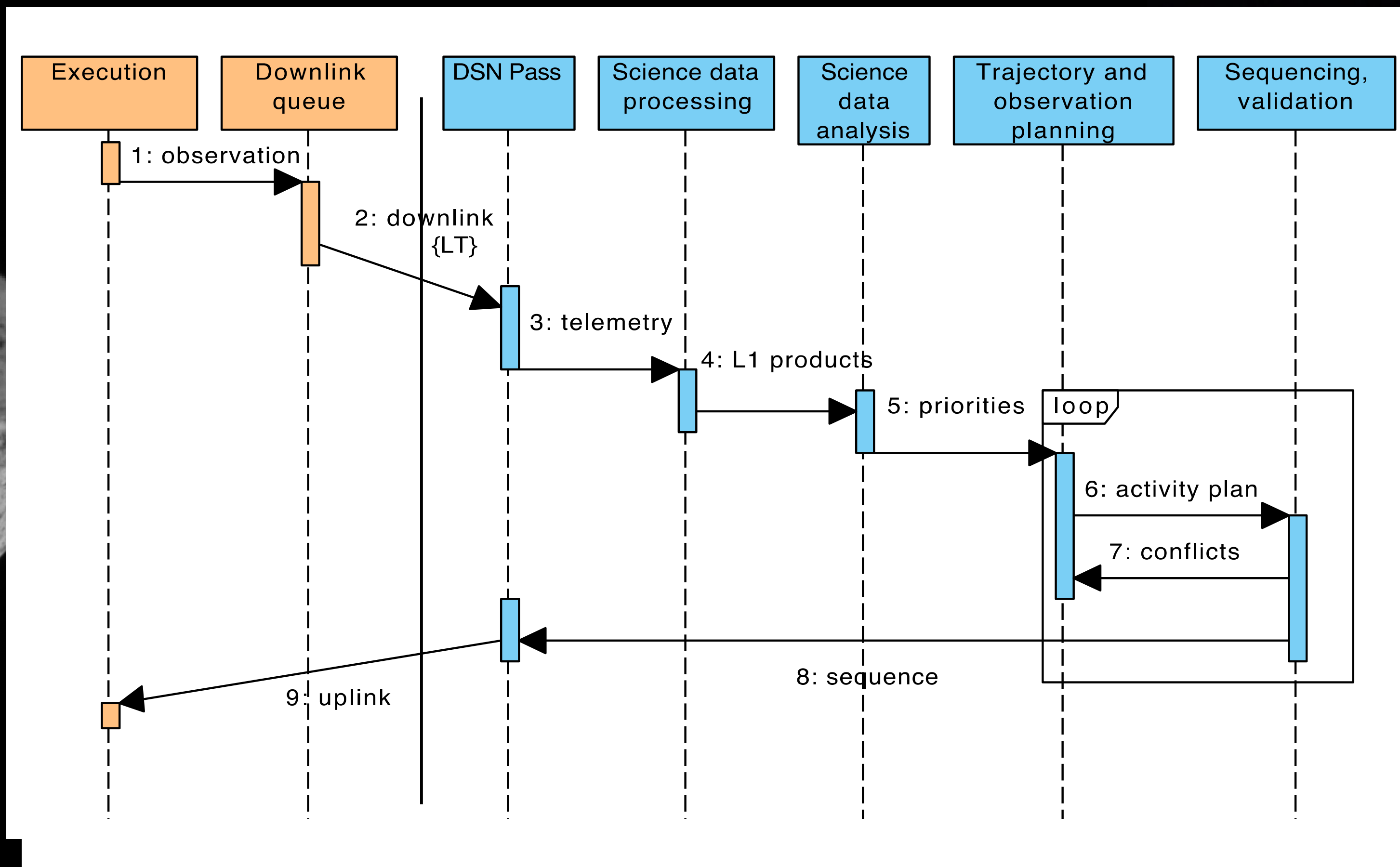
Surface activity is transient, time-variable



Images: Tempel 1 (Deep Impact) PIA 02142, NASA/JPL/UMD

Reaction time limits total science yield

time



S/C

Ground

Images: Tempel 1 (Deep Impact) NASA/JPL/UMD
Earth: (Apollo) NASA

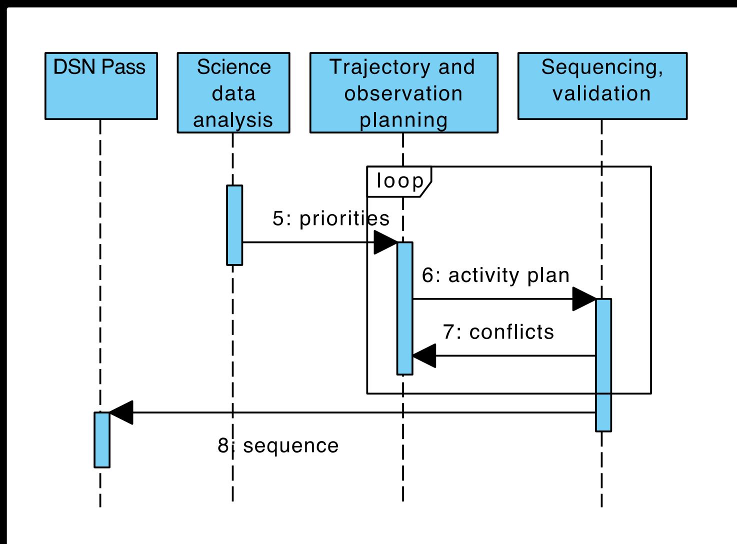
Our challenge: enable rapid tactical operations for primitive bodies missions

- Improve planning turnaround
- Achieve MER-style operations under deep space constraints
- Speed the "learning curve"

Benefits

- Achieve mission objectives faster
- Improve resilience to anomalies
- Collect data from targets of opportunity
- Enable time-domain science investigations
- Enable smarter flybys with high-res targeted data

Approach: Faster replanning cycle



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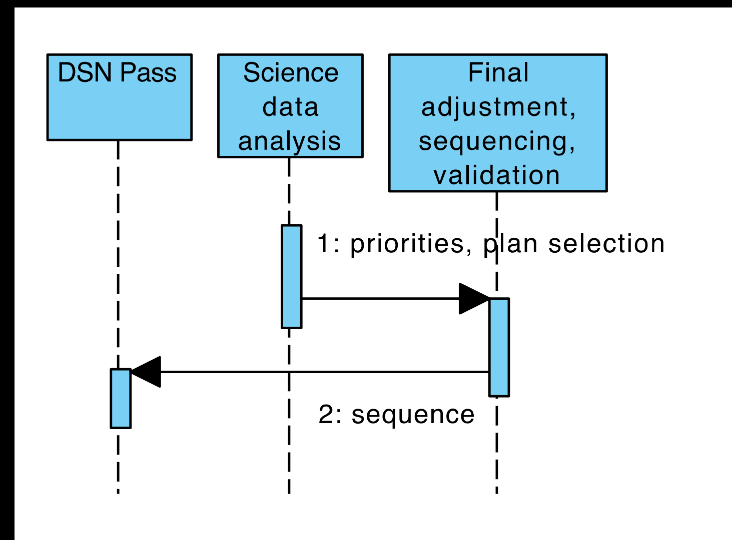
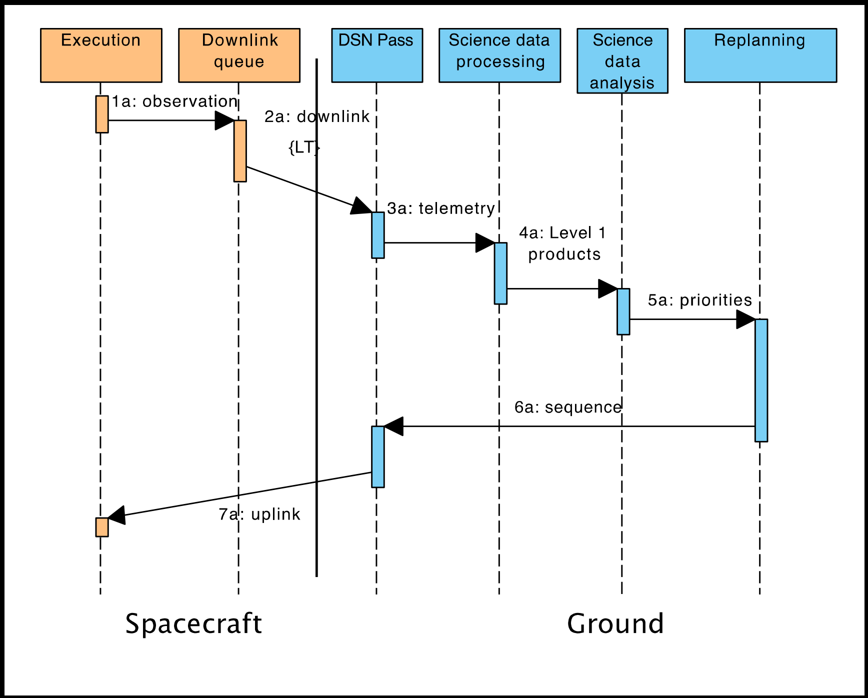


To this

- Contingency planning (maintain a pool of valid plans for different objectives)
- Expedited ground science data analysis, smart "quicklook" products

Approach: Onboard data analysis



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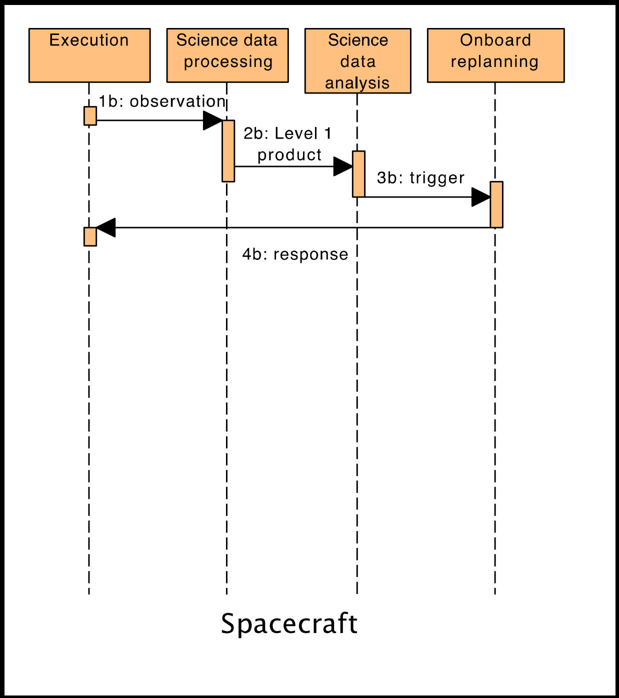
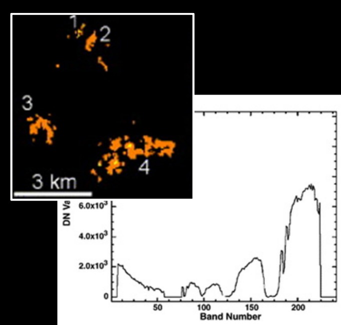


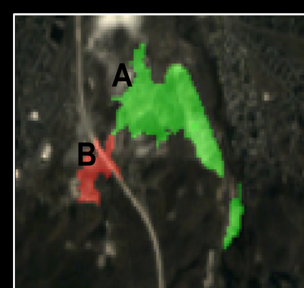
To this

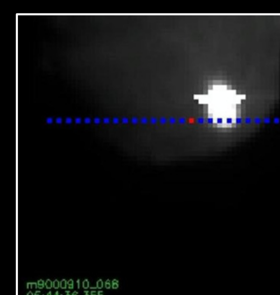
- Selective targeted data collection and return to exploit targets of opportunity (erosion features, outgassing, etc).
- Push time-critical decisions across the light-time gap

Technology heritage

	ASE (EO-1)	HiiHAT Demo (EO-1)	Autonav (Deep Impact)	AEGIS (MER)
Objective	Prioritize downlink (thermal detection)	Prioritize downlink (spectral mapping)	Trajectory updates during encounter	Target detection, followup
Data analysis	~2hr	5hr	1.5-8h	10-20m
Trajectory Generation	-	-	10-200m	-
Activity Planning	30m	-	-	2m
Followup execution	90m	-	1m	<1m
Total reaction time	~4hr	-	2-10h	<25m
Reference	[Chien 2005, Davies 2006]	[Bornstein 2011]	[Ridel 2001]	[Estlin 2011]



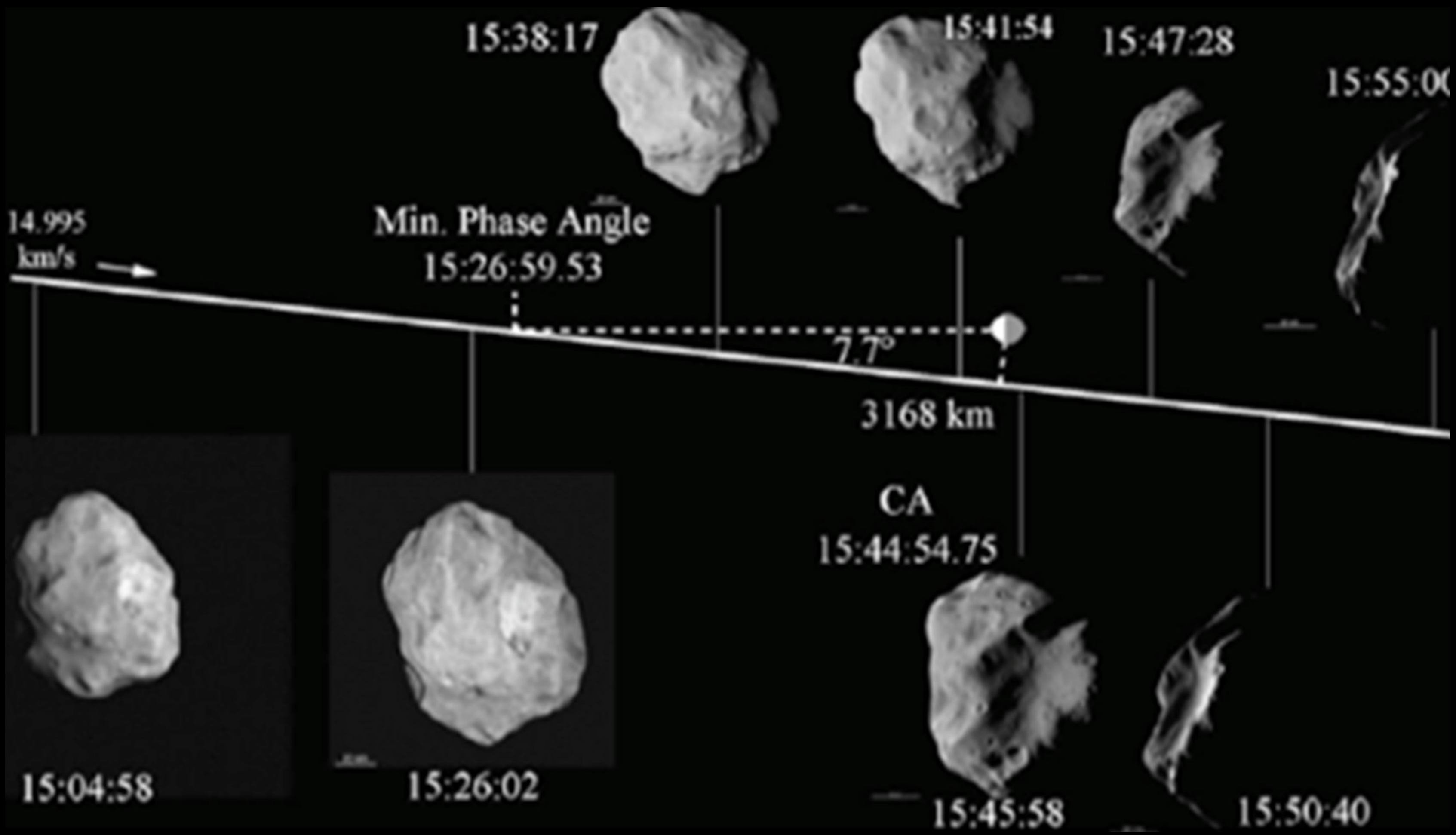




This study

- Quantify benefits of agile operations for science yield
- Simulate mission data collection under different assumptions about reaction time
- Two scenarios
  - Smart flyby (Lutetia 21)
  - Encounter and mapping for proximity ops site selection
- Use representative trajectories from Rosetta encounters

Lutetia 21 encounter by Rosetta



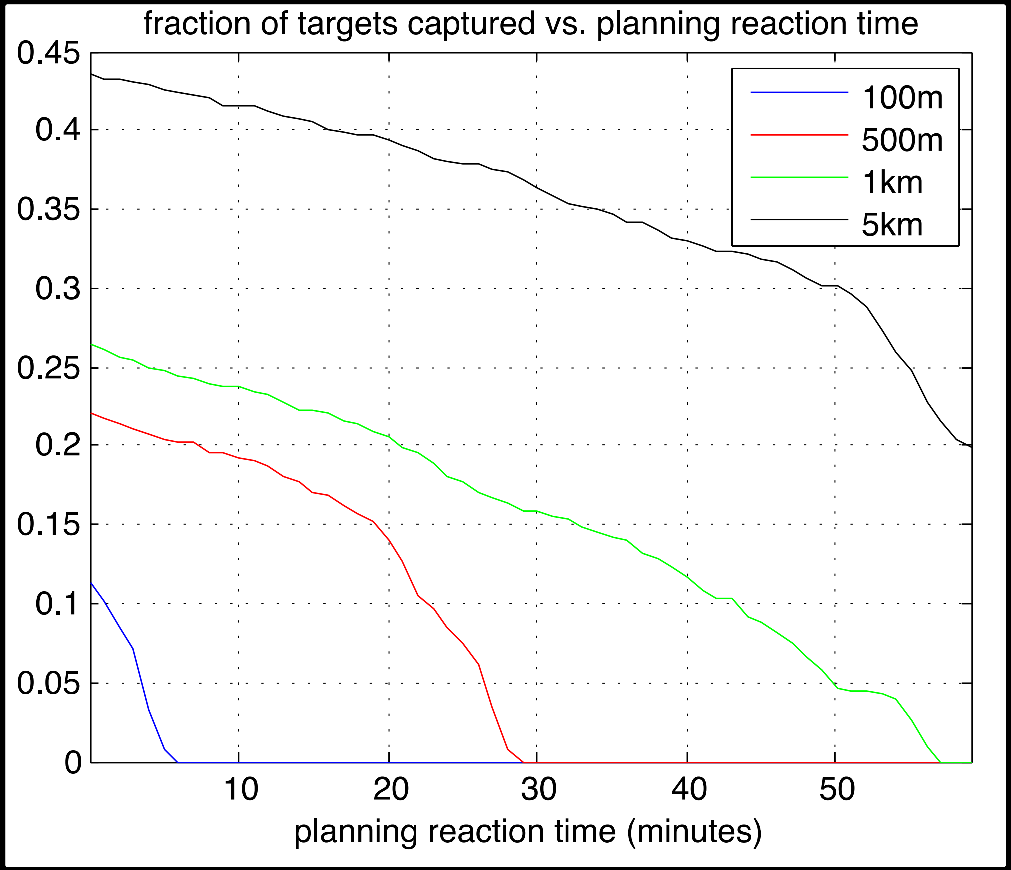
Smart flyby performance

Simulated targets of varying sizes, distributed randomly

- erosion features
- surface activity
- spectral anomalies

Enforce illumination, geometry constraints

What fraction of the time can we capture the target with high-res images, VNIR or UV spectroscopy?



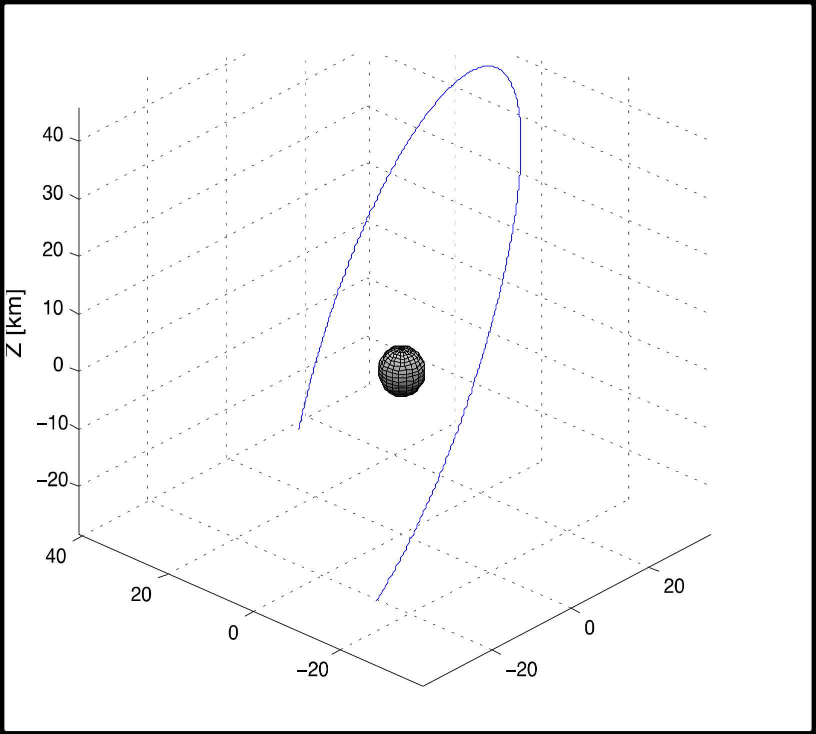
Prox ops site selection

Goal: characterize activity level of candidate prox ops sites with high-resolution imagery

Simulate Rosetta mapping trajectories (very approximate, since real orbits are non-Keplerian)

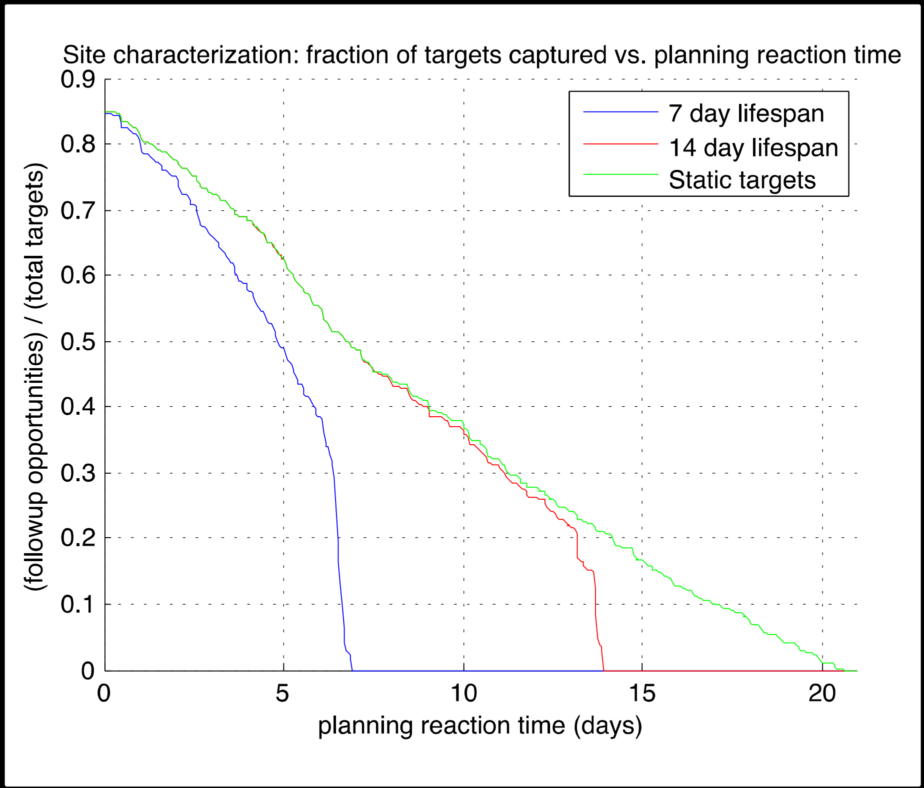
Three-week trajectories will image potential landing sites prior to landing

Candidate sites are randomly distributed, and may have active and quiescent periods



Prox ops site selection performance

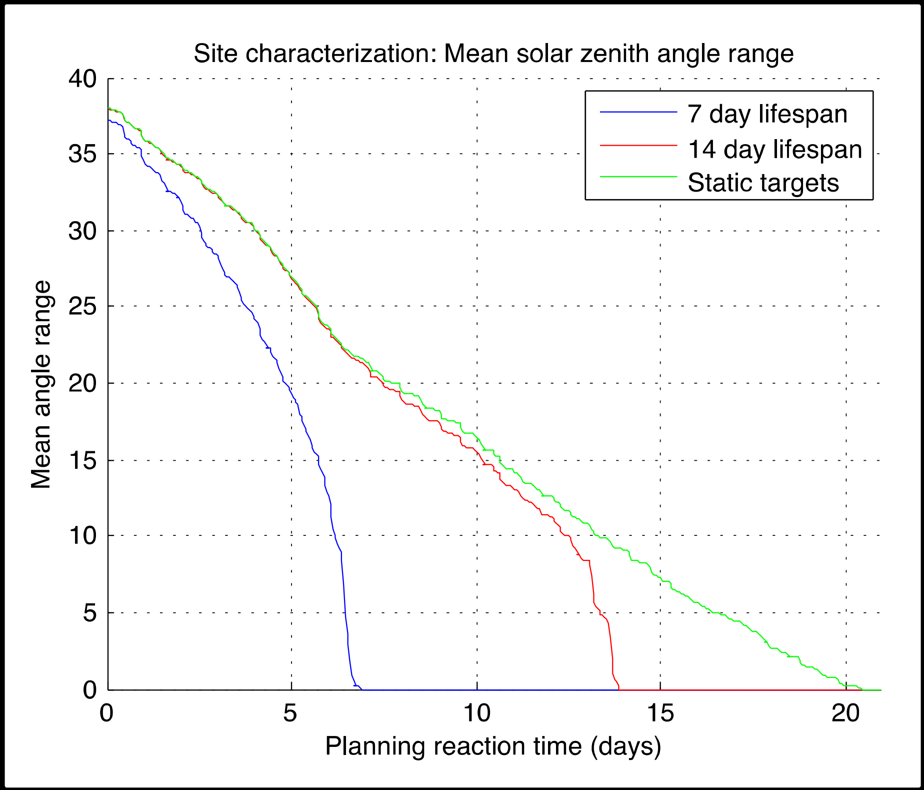
Right: potential for followup imaging of surface activity for different feature lifespans



Prox ops site selection performance

Right: solar angle range apparent in images, as a function of planning turnaround, for different activity periods

Larger angle ranges are desirable, but require fast turnaround to achieve



Agile ops techniques across missions

		Missions									
		Asteroid / inert					Comet / active				
		Dawn-style mapping	Hayabusa II	OSIRIS-Rex	Trojan Tour	Chiron Orbiter	Rosetta	Comet Hopper	CSSR	CNSR/CCSR	Coma Sampler
Mission and science unknowns	Morphological units	x	x	x	x	x	x	x	x	x	x
	Surface composition, mineralogy	x	x	x	x	x	x	x	x	x	x
	Localized targets (boulders, crater walls, etc)	x	x	x	x	x	x	x	x	x	x
	Satellites	x									
	Plume activity, distribution over space and time						x	x	x	x	x
	Gravity field	x									
	Location of site for sampling/landing		x	x			x	x	x	x	
	Surface conditions at sample site		x	x			x	x	x	x	
	Rotation rate and pole location	x	x	x			x	x	x	x	x
	Spacecraft performance / faults	x	x	x	x	x	x	x	x	x	x
Applicable ground ops technologies	Single-cycle trajectory/observation selection	x	x	x	x		x	x	x	x	x
	Fast instrument data processing	x	x	x	x		x	x	x	x	x
	Fast instrument data interpretation	x	x	x	x		x	x	x	x	x
Applicable onboard technologies	Trajectory replan (fault or hazard recovery)		x	x			x	x	x	x	x
	Observation replan (opportunistic targeting)	x	x	x	x		x	x	x	x	x
	Morphological pattern recognition	x	x	x	x		x	x	x	x	x
	Spectral pattern recognition	x	x	x	x		x	x	x	x	x
	Plume/change detection						x	x	x	x	x
	Satellite detection	x									
	TRN / optical navigation for prox. ops		x	x			x	x	x	x	
	Onboard planning / execution for prox. ops		x	x			x	x	x	x	

Conclusions

- Primitive bodies exploration requires innovative operations strategy
- Technological solutions will play an important role
  - Better ground-side automation and fast replanning
  - Limited transfer of authority for time-critical decisions
- Ops approach might influence mission planning and instrumentation
  - Smart targeting for Trojan and Main Belt Asteroid tours
  - High-cadence operations to accelerate prox ops schedules